Nanolaminate Hybrid Mirror Technology and X-Sat Flight Experiment

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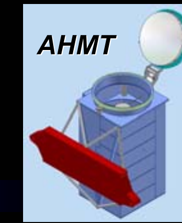
Outline



- Motivation for Developing New Mirror Technology
- Description of an Actuated Hybrid Mirror (AHM)
- The X-Sat II Experiment
- Summary
- Questions

Current Large Optics Paradigm

- Long lead times – several years to produce
- Significant investment - $10s M per mirror
- Limited supply of ultra-low expansion (ULE) glass and vendors
- Manufacturing difficulties in light-weighting
- No ability to correct mirror figure on orbit

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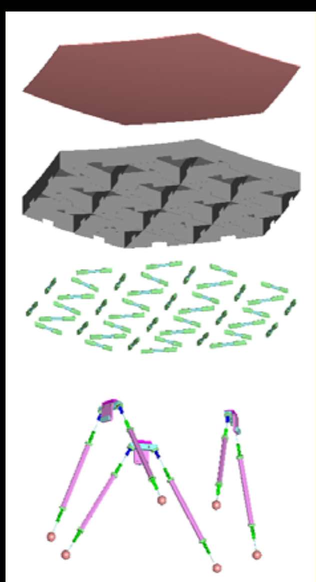
Potential of Hybrid Mirrors

- Rapid manufacturing
  - Replication & casting reduces time from years for glass to several months for hybrid
- Significantly lower production cost
  - Common materials and production hardware
- Low areal density (~7 kg/m^2)
  - Larger mirrors, higher orbits
- Actuation enables:
  - On orbit figure correction
  - Relaxation of manufacturing tolerances and testing

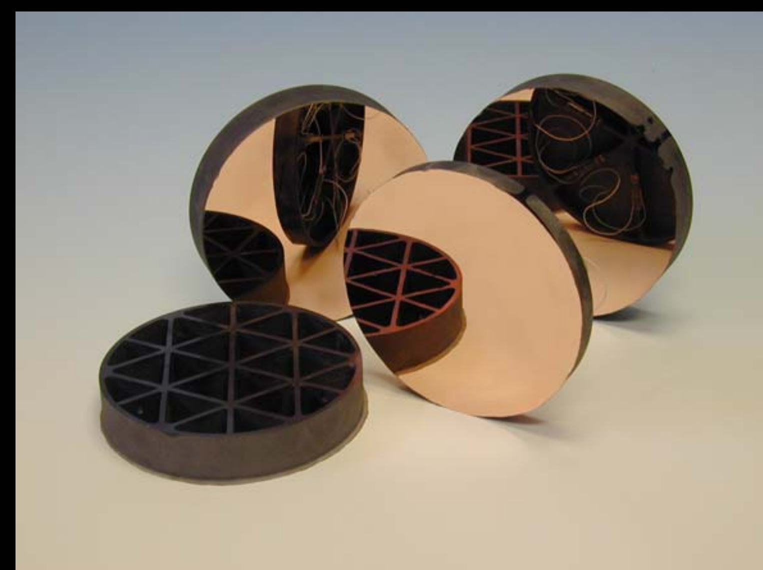
Description of an Actuated Hybrid Mirror

Actuated Hybrid Mirror (AHM)

- The combination of distinct technologies
  - **Facesheet:** Nanolaminate foil (DOE/LLNL)
  - **Substrate/figure control:** Actuated silicon carbide (Xinetics, Inc. Devens MA)
  - **Metrology hardware and algorithms: W**avefront sensors (NASA/JPL)
- AHM represents a stepping stone to a future, all nanolaminate-based mirror system



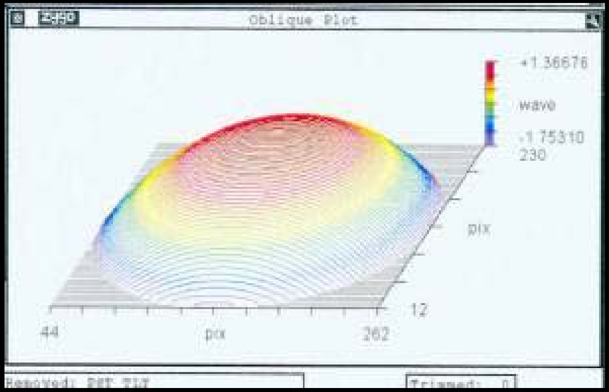
Nano Laminate	0.4 kg/m²
SiC Substrate	4.8 kg/m²
Actuators	1.2 kg/m²
Bipods	0.4 kg/m²
Harness	0.2 kg/m²
Total	**7.0 kg/m²**



15-cm Flat SPA Mirror
Optical Data for Nanolaminate Bonding Process

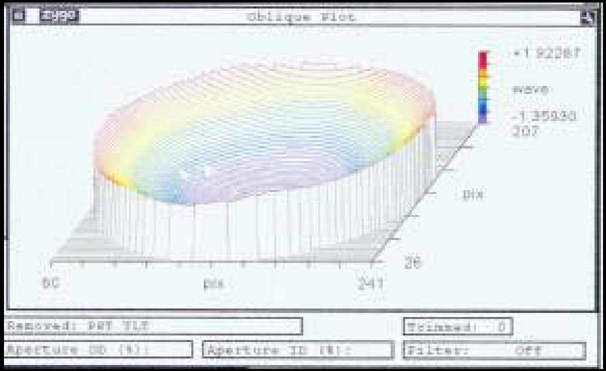
Before Bonding

Foil on mandrel
- **PV: 3.120 λ**
- **RMS: 0.898λ**
- **Power: -3.179 λ**



After Bonding

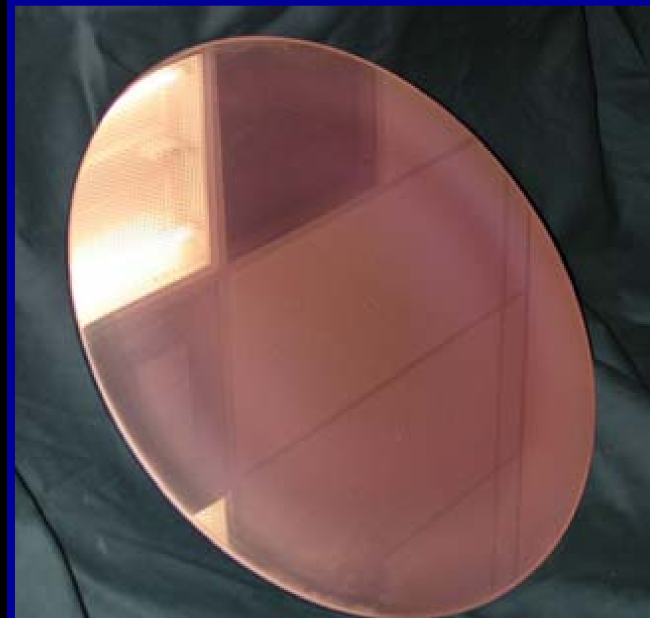
Foil Bonded to SiC substrate (mandrel removed)
- **PV: 3.28λ**
- **RMS: 0.8810λ**
- **Power: 3.064λ**



Nanolaminate Foil

Cross-Section

Finished Foil



600 Å Copper

100 Å Copper-Zirconium

- **Multi-layer metallic foils grown by sputter deposition onto metal or glass mandrel**
- **Very thin (~0.1 mm), lightweight, flexible with good optical performance**
- **Final shape and surface finish defined by mandrel**
- **Low areal density – 0.2 kg/m^2 to 0.8 kg/m^2 depending on material & thickness**
- **Rapid Manufacture - ~ 48 hours per foil independent of diameter**
- **15 Foils made off single mandrel with no degradation to mandrel**

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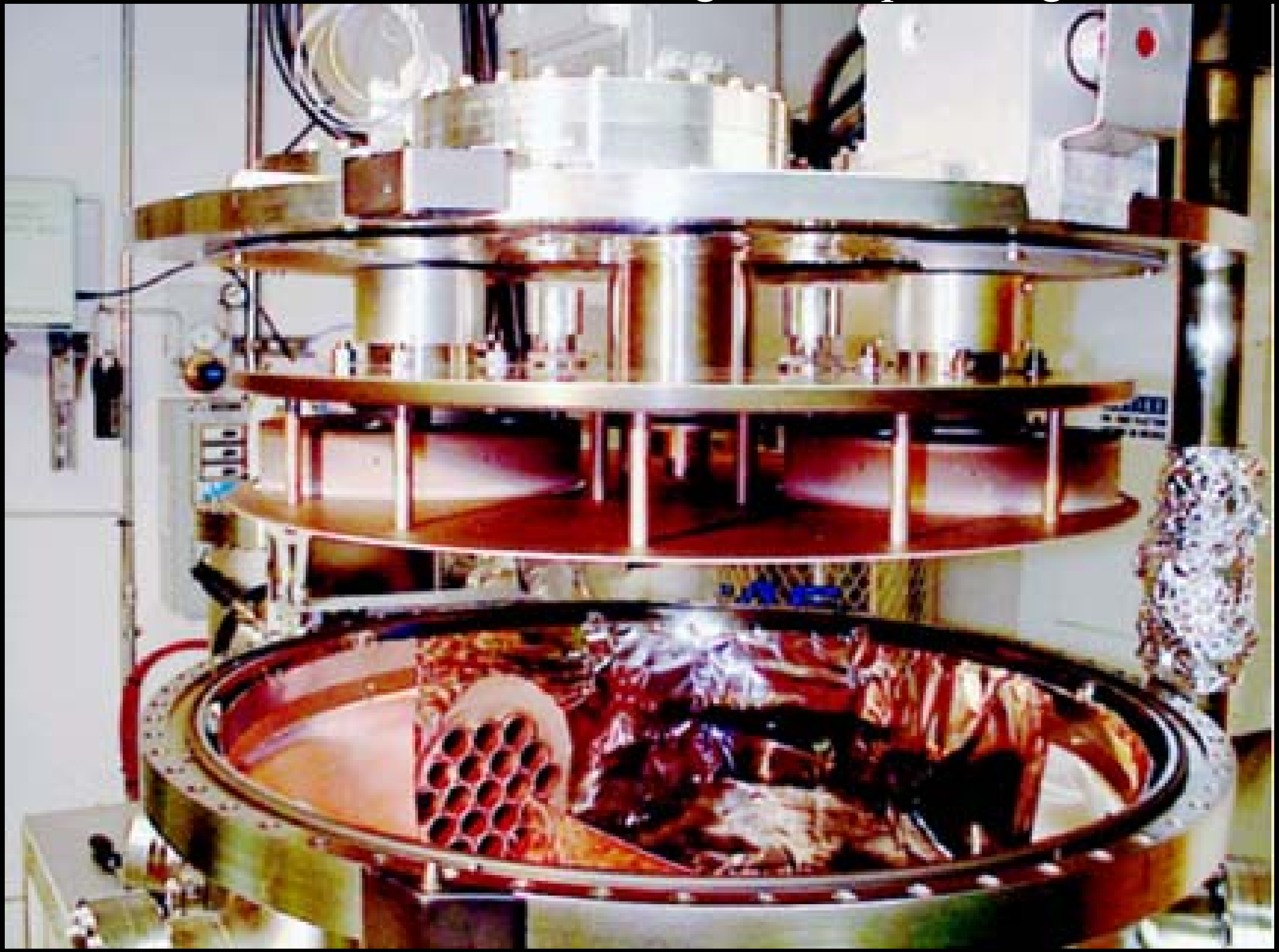
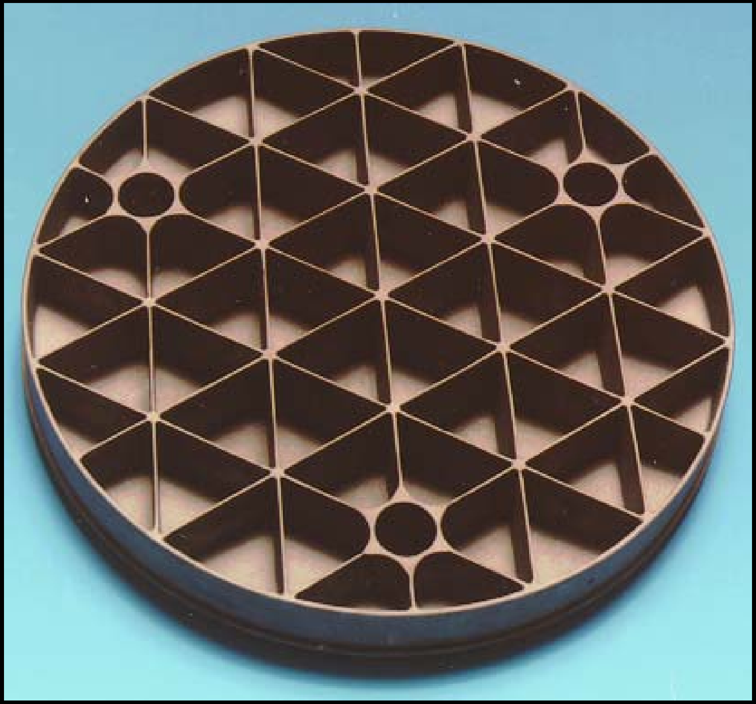
Nanolaminate Foil Fabrication

DC magnetron sputtering chamber



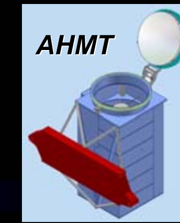
Actuated SiC Substrate

- Leverages work under joint MDA/NRO program
- Lightweight, very stiff, highly dimensionally stable material
- Nanolaminate facesheet obviates need for polishing to optical tolerances
- Utilizes lead-magnesium-niobate (PMN) low-power ceramic actuators for figure control
  - Negligible hysteresis
  - Minimal creep
  - No poling-related aging



AHMT

The X-Sat II Experiment

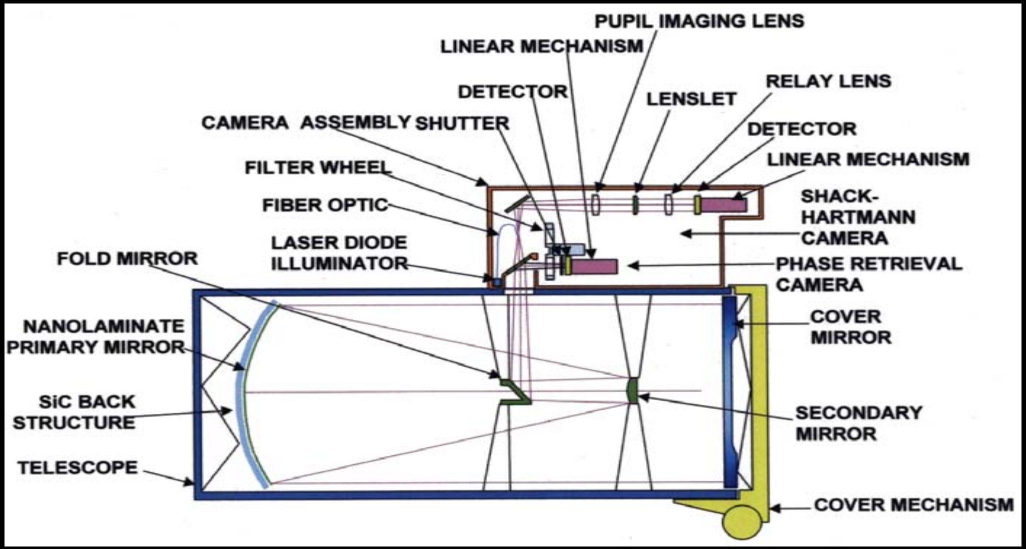


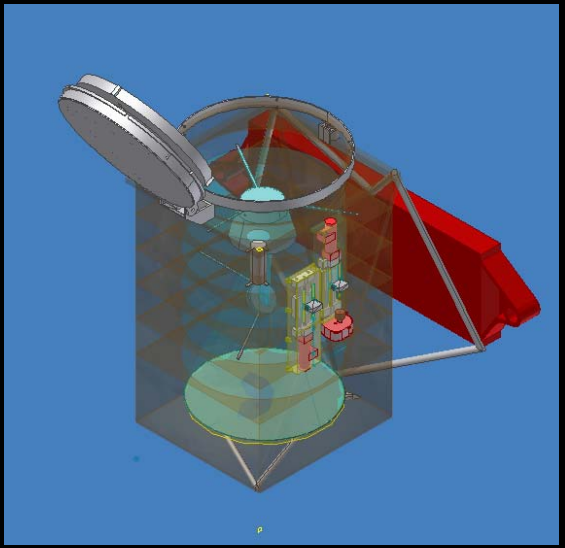
Objectives/Goals

- Design, build, test and fly a telescope utilizing a lightweight, rapidly manufacturable primary mirror
- Demonstrate near-diffraction limited performance in an operational space environment (microgravity, thermal loading, vibration)
- Obtain opportunistic images of the earth and celestial objects
- Achieve TRL 7 by 2007

X-Sat Payload

- Cassegrain Telescope with 0.75m Actuated Hybrid Mirror as Primary Mirror (PM)
  - Phase Shack-Hartman and Retrieval cameras for coarse & fine wave-front sensing, mirror metrology & control.
  - 1024x1024 CCD focal plane array for earth/sky imaging
  - Wide-field spotting camera for visual reference
- Proven heritage for many key components: focal plane array (flt spare, Mars Pan Camera), filter wheel (flt spare, Mariner), shutter mechanism (flt design, Stardust/Cassini), cover door and latch mechanism (flt design, Genesis)





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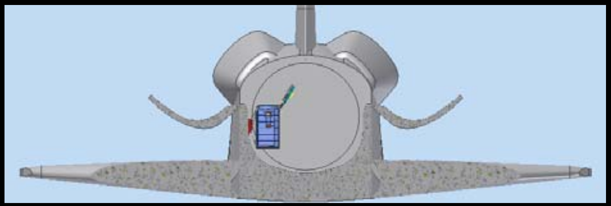
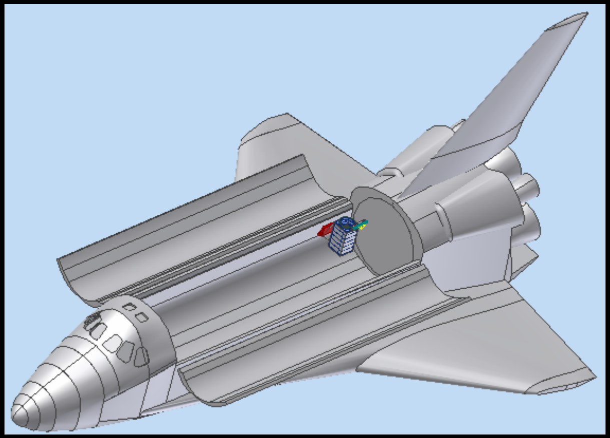
X-Sat Experiment Bus

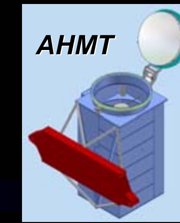
Hitchhiker sidewall mount flown in STS cargo bay

- All necessary experiment support functions provided through well-defined interfaces
  - Power, Avionics, data acquisition, communication
- Shares Cargo Bay with other Payloads
- Experiment will not require specialized shuttle crew training
- Payload Integration/management, data transfer, telecom, and ground support provided by NASA Goddard Space Flight Center
- Letter indicating NASA sponsorship

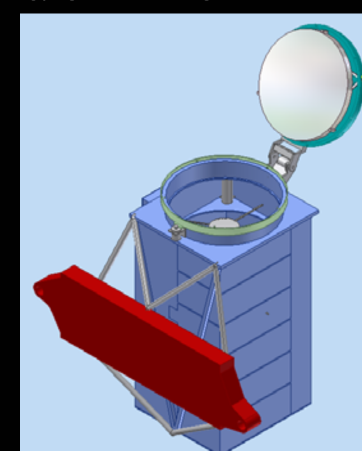




On-Orbit Experiment



- Two-phase test and demonstration of AHM
  - Phase 1: Mirror Metrology, Actuation Testing, and Figure Control
    - Performed prior to opening of Aperture Cover
    - Integral heaters provide thermal disturbance
    - Most of Experiment's Objectives
  - Phase 2: Earth/Sky Image Collection under thermal & spacecraft vibration conditions
    - Near real-time figure control of PM



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Experiment Operations Timeline

Experiments	Door closed	Door open	Fast close door/ WFS/open door	SH WFS	PRC WFS	Phase retrieval	Phase diversity	Prescription retrieval	WFC commands PM actuators	Thermal closed-loop control	Thermal open-loop control	Heater thermal disturbances	Shuttle dynamic disturbances	Accelerometers monitored	View ground	View space	Launch	Expt power-up	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Re-entry
1. Initialization	●			●	●	●		●	●		●		○	○				■	■										
2. Long-term stability, door closed	●			○	●	●		○	○	●			○	○					■	■	■	■							
3. WF control of thermal disturbances	●			●	●	●		○	●	●		●	○	○							■	■							
4. Thermal control of thermal disturbances	●			●	●	●		○	○	●			○	○									■						
5. Measure stability, door open		●	●	●	●	●		○	○	●			○	○	○	○								■	■	■	■	■	
6. Deep-space observations		●	●		○	●	○	○	○	●			○	○		●									■		■		
7. Ground observations		●	●		○	●	○	○	○	●			○	○	●											■		■	
8. WFC calibration	●			●	●	●			●	●			○	○							■								
9. On-orbit dynamics													●	●				■	■	■	■	■	■	■	■	■	■	■	

● = Primary ○ = Secondary

Sequencing and duration of open-door experiments is notional, pending detailed mission planning

Summary

Summary

- Nanolaminates and nanolaminate hybrids are creating a new paradigm for lightweight, large aperture primary optics
  - Overcomes many issues of conventional glass mirrors
- An AHM X-Sat will provide credible flight heritage and boost TRL to 7 by 2007
- New capabilities enabled by actuation such as on orbit figure correction

Questions?

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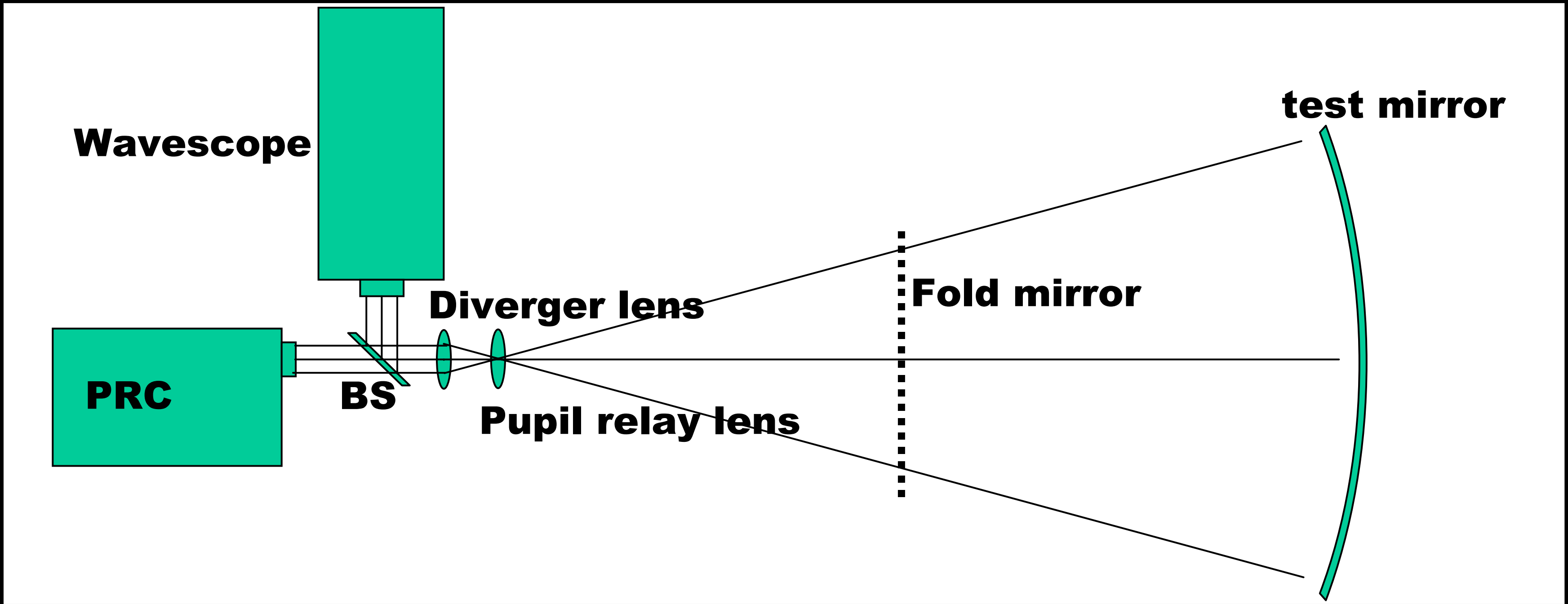
Backup Charts

Lab Metrology



- Lab setup utilizes WF sensor modules to simplify operations
  - AOA Wavescope Shack-Hartman sensor provides large capture range for initial phasing
  - JPL Phase Retrieval Camera (PRC) provides a source, high-resolution image-based WF sensing, and direct imaging for scoring
- Fold mirror permits off-the-table vertical placement of the test piece